# What is the Future of Technology Roadmaps for Optoelectronics Packaging?[1]


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October 2002

[1] Identification of products herein does not imply recommendation by NIST, nor does it imply that such products identified are necessarily the best available for the purpose.

[2] Any opinions expressed here are my own, and not necessarily those of NIST.

# Outline

- Technology roadmap tutorial
- Lessons learned from semiconductor roadmaps
- Roadmaps that mention optoelectronics packaging
  - International Technology Roadmap for Semiconductors (ITRS)
  - National Electronics Manufacturing Roadmaps (NEMI)
  - Institute for Interconnecting and Packaging Electronic Circuits (IPC)
- Technical Challenges/Gaps
- Conclusions and Next Steps

# Who leads a technology roadmap? There are many answers!

**(industry – government – university)**

**companies lead**

**universities lead**

**government agencies lead**

# What is a technology roadmap?

**A technology roadmap in the context of this discussion is a documented consensus-based plan that <u>industry</u> leads with inputs from the <u>research community</u> and if appropriate from <u>governments</u>.**

# What drives a technology roadmap?

**Three key drivers are:**

1) **Market share dynamics among competing technologies**
2) **Expectations of the market not being met**
3) **Costs of doing business and maintaining its infrastructure becoming too great for one company or one country to assume.**

# Prerequisites for Successful Roadmaps – Consensus-Based Plans

**Decision-makers from different organizations**
**<u>alter</u> their attitudes towards one another, and thereby,**
**<u>enable</u> more cooperation,**
**<u>share</u> pre-competitive information, and**
**<u>develop</u> open interfaces and standards.**

**That is, a change from business as usual.**
**The changes in business practices are more important than the written roadmap-document itself.**

# Prerequisites for Successful Roadmaps – Consensus-Based Plans
(Continued)

They are dynamic –
reviewed/updated annually and
re-written at least biennially.

They are most effective when they increase industrial cooperation and produce positive changes in how companies work together on pre-competitive R & D and on strengthening their supply chains.

# Outcomes from the ITRS
# (Si CMOS)

**Moore's Second Law:**
**Over many generations of technology developments, the Si CMOS industry has improved performance and functionality by <u>integer factors</u> with only <u>incremental increases</u> in production costs from one generation to the next.**

**Many observers credit consensus-based planning and deliberate roadmapping efforts for the sustained average annual growth rate of 15% for the silicon semiconductor industry over this past decade.**

# Some Collaborative Efforts of Si CMOS Companies

— SRC operates globally to provide competitive advantage to its member companies (over 25); delivers relevantly educated technical talent and early research results; and plans and manages a program of basic and applied university research

- MARCO – a relatively new independent subsidiary of SRC to expand pre-competitive, cooperative, long-range, applied microelectronics research at U.S. universities.

— International SEMATECH member companies cooperate precompetitively in lithography, interconnect, front end processes, advanced manufacturing methods, and environment, safety and health semiconductor manufacturing technologies; and share expenses and risks to accelerate development of advanced manufacturing technologies that will be needed to build tomorrow's most powerful semiconductors.

## Technology Roadmaps

**" A *roadmap* is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field."**

**"Roadmaps allow our industry leaders to communicate convincingly with those in government and business regarding their support of our goals."**

**"Roadmaps are working now in industry and they are beginning to gain a stronghold in science**."

----- Robert Galvin, Chairman of the Executive Committee of Motorola, editorial in *Science* **280**, 8 May 1998, p. 803.

# Why is a technology roadmap useful?

A technology roadmap is often an effective technique to:

1) Reduce uncertainties in investments
2) Use changes among competing technologies as opportunities
3) Increase the probability for more robust economic performance
4) Guide critical research
5) Assist in setting priorities for resource allocations and
6) Accelerate the rates of both technology development and deployment.

# You should be interested in technology roadmaps because:

1. Lose less money to competing technologies

2. Make more money by enabling new technologies - examples Optical interconnects for scaled CMOS (co-integration of compound semiconductor lasers, LEDs, and photodiodes) with CMOS processes below the 65 nanometer node, about 2007, in the ITRS 2001. This is considered to be a way to solve interconnect delays and cross-talk issues with conventional interconnects.
   CMOS industry wants to know when lasers could be co-integrated with CMOS, ITRS 2001 Meeting, 18 July 2001, San Francisco.

# Lessons Learned from Si CMOS Roadmap

- Many technology barriers, once thought to be of concern to a few companies, are common through out the industry. Overcoming such barriers offers an appropriate focus for technology roadmaps.

- Prior to mid 1980's, most Si CMOS companies assumed that over 50% of what they knew was proprietary and not to be part of consensus-based planning and collaborations.

- From the late 1980's to today, most Si CMOS companies found that over 50% of what they know is not proprietary and may be shared with other companies for a globally more competitive industry.

# Lessons Learned from NEMI

- **Discussions with senior industrial managers for acceptance.**
- **Worked in 1991 from a " then virtual product - PDA" as a basis for bringing all stakeholders together.**
- **Challenge was to have a large enough effort to be effective, but still focussed enough to have measurable progress.**
- **Everyone has similar problems. Much IP is common to everyone. Industry moves faster when these are recognized and common problems are solved.**

# Industry's Role?

- Industry should lead in consensus based-planning
  - Compete with alternative technologies
  - Converge on requirements for base materials to lower costs and increase performance
  - Downsizing requires smarter investments determined in part by consensus-based planning

- But, governments may facilitate consensus-based planning.

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# Academe's Role?

- Invent new and alternative technologies.
- Provide well trained people that industry and government want to hire.
- Provide long-term knowledge base to support future marketable technologies.
- Be partners in addressing research challenges such as fabrication processes and equipment for new high-performance materials and systems.
- Receive industrial and government feedback for development of university programs.

# Trends

Technology Focus

# The current collapse of the fiber-optics business... What's next ?

atip

YOLE DÉVELOPPEMENT


## Summary

Today, it is about 500,000 employees who have been laid off from the optical telecom business. From large groups to smaller companies, everyone has been affected (34,500 jobs lost for Alcatel; 10,000 for Cisco; 49,000 for Nortel; 16,000 for JDS Uniphase...).

This tsunami is explained by a lack of short-term visibility and by the brutal discovery of an over-capacity and too much inventory... Moreover, companies have paid tremendous prices for technologies which revealed to be far from being mature and most of the people was aware that the optical components market was a low-volume market for the years to come. The fever which developed was an irrational one. Because of over-estimated predictions of the needs for optical components for a growing Internet network, one has entered a vicious circle where every companies ran to be bigger, to have a broader range of technologies... than its competitors.

These events have led to a new deal in the optical components business. And despite this wreckage, almost 30 new startups have been created in Europe over the period 1999-2002. The new FABOPTO report


Adapted from ATIP email received July 2002

www.atip.org/fabopto.pdf

# Trends
(continued from previous slide)

- **About 500,000 employees have been laid off from the optical telecom business.**
- **This tsunami is explained by a lack of short-term visibility *[vision],* …by …over-capacity and too much inventory.**
- **Companies paid tremendous prices for technologies which …*were far from maturity*.**
- **Because of over-estimated predictions of the needs for optical components,… companies ran to be bigger *and* to have a broader range of technologies … than *their* competitors.**

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## Status of Telecommunications Industry

“ … transformation … as the industry goes from a really proprietary industry where every company has their own set of standards to more modular building block(s), open interface(s), standard building block(s), … somewhat like the computer industry is today.”

--- Craig Barrett, CEO Intel, in New Technology Week, 15 July 2002, page 2, on today’s troubles in the telecommunications industry.

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Where would it be today if OE had an international industrial consensus that involves R&D, materials suppliers, equipment vendors, and manufacturers?

# Where Is Optoelectronics Packaging Discussed?

- **NEMI (December 2000 Report and 2002 Revision)**
- **ITRS (December 2001 and 2002 Update)**
- **IPC (Draft IPC/J-STD-040, March 2002) – standards roadmap, not a technology roadmap in the context of this talk**
- *OIDA (North America)*
- *OITDA (Japan)*
- *MEL-ARI-OPTO (Europe)*

**But unlike Si CMOS, no consensus on priorities and on time-lines when technical goals for NEMI, ITRS, and IPC in optoelectronics packaging are to be met.**

# Cell phone: Evolutionary RF Specifications

| Parameter | Metric | 2001 | 2003 | 2005 | 2011 |
|---|---|---|---|---|---|
| RF section cost (for a given function) | Relative to costs in 2000 | 0.7 | 0.35 | 0.17 | 0.05 |
| Number of freq bands | | 2 | 3 | 3 | 4 |
| Number of Antennas (Diversity) | | 1 | 2 | | |
| Number of Modulation formats | | 2 | 3 | | |
| Data transmission rate (peak)? | kb/s | 14 | 160 | 1500 | |
| Transmit Peak-to-Average Ratio (worst case) | dB | 4 dB | 3 dB | | |
| Talk time | minutes | 90 | 120 | | |
| Battery Voltage | V | 3.3 | 2.7 | 1.5 | 1.2 |
| RF section area | $mm^2$ | 1500 | | | |
| RF component thickness | mm | 2.5 | 1.5 | 1.5 | 1.0 |
| From Handheld emulator: | | | | | |
| Average Component I/O Density | I/O per $cm^2$ | 55 | 80 | 100 | 160 |
| Max Component I/O Density** | I/O per $cm^2$ | 175 | 240 | 290 | 400 |
| I/O per Component, avg. | # | 3.6 | 4.0 | 4.4 | 5.0 |
| Package I/O Pitch (Perimeter) | mm | 0.5 | 0.5 | 0.5 | 0.5 |
| Max I/O per package | I/O per pkg | 256 | 288 | 312 | 360 |
| Flip Chip I/O Pitch (Area) | mm | 0.25 | 0.25 | 0.20 | 0.10 |
| Substrate Lines and Spaces | microns | 60 | 35 | 30 | 20 |

From NEMI RF Components 2000 Technology Roadmap

# Product Sectors from NEMI, ITRS, and IPC

| Product Sector | Approximate Cost | Characteristics |
|---|---|---|
| Low cost | < $300 | High volume consumer products for which cost is the primary driver |
| Hand Held | < $1000 | Battery-powered products drivern by size and weight reduction |
| Cost/Perforamance | < $3000 | Products that seek maximum performance within a few thousand dollar cost limit |
| High Performance | > $300 | High-end products for which performance is the primary driver |
| Harsh Environment | | Products which must operate in extreme environments |

Coordination among NEMI, ITRS, and IPC on packaging roadmaps.

## NEMI – Critical Issues in Optoelectronics Packaging

- **Low Cost Packaging**
  - Demonstrate plastic packaging for high performance applications.
  - Deploy passive alignment technology for high end applications.
  - Produce faster, higher performance, and miniaturized packages
  - Incorporate increased levels of optical/electrical integration.
  - Provide cost effective assembly technologies.
  - Develop innovative new materials and design technologies.
  - Develop thermal solutions for high power 1 to 2 Watt packaged lasers.
- **Hybrid Integration**
  - Design and manufacture of specialized assembly equipment.
  - Combine electronic and photonic assemblies for effective packaging.
  - Develop packaging processes that are compatible with CMOS VLSI and compound semiconductor processes.
  - Develop alignment tolerant designs.

## **NEMI – Critical Issues in Optoelectronics Packaging** (continued)

- **Standardization**
  - Develop standards for O/E modules, cables, and connectors as steps towards larger markets.
  - Lack of standards for optoelectronic and electronic packages hinders transition to commercial automations.
- **40 GHz Packages**
  - It is not clear that existing technologies will be appropriate for 40 GHz.
  - A collaborative effort among package component suppliers, optical module/device/subsystem manufacturers, and network equipment manufacturers is necessary.

## **NEMI – Critical Issues in Optoelectronics Packaging** (continued)

- **Business Models and R & D**
  - Present economic conditions and increased outsourcing have led to a global decrease in R & D for packaging.
  - A shift in R & D efforts for optoelectronics packaging from North American companies to Asia and Europe may be occurring.
  - Present R & D investments do not address effectively the increasing package cost that may greatly exceed die cost.
  - Technical challenges are more complex and broader in scope; drive the need for higher skill levels; and increases interdependencies among packaging, electronics, and materials (I.e., supply chains.

## ITRS – Critical Issues in Optoelectronics Packaging

- **Technical**
  - High data rates and low signal levels of converted optical signals.
  - Integration of optical functionality into modules. Passive devices (array waveguide gratings, filters, and splitters). Active devices ( lasers, modulators, detectors, amplifiers, switches, and attenuators).
  - Aligning optical paths and maintaining alignment under all service conditions. Transmitter (laser) alignment tolerances are even more stringent with mode size about 10 :m.
  - Hermetic packaging to keep optical path free of contamination.
  - Fiber feed-throughs in hermetic package add complexity and cost.
  - Controlling strain-induced birefringence when mounting optical components.

## **ITRS – Critical Issues** (continued)

- **Technical** (continued)
  - Better understanding of materials properties to engineer optoelectronic packages (Si, SiGe, AlGaAs, InP – all in one package).
  - Understanding thermomechanical effects and material interactions for reliable packages.
  - Understanding viscoelastic properites of adhesives to control environmental stressing behavior of fiber alignment mountinges.
  - Designing systems that include optical, electrical, thermal, and mechanical requirements of packages.
  - Developing validated, integrated computer assisted design tools.
  - Integrating thermo-electric (Peltier) coolers and dissipating waste heat - Future high packing densities and very high data rates (10 Gbps to 160 Gbps) will make thermal control more challenging.
  - Meeting needs such as thermal stability, refractive index, and tolerances of optical devices and materials during assembly.

## **ITRS – Critical Issues** (continued)

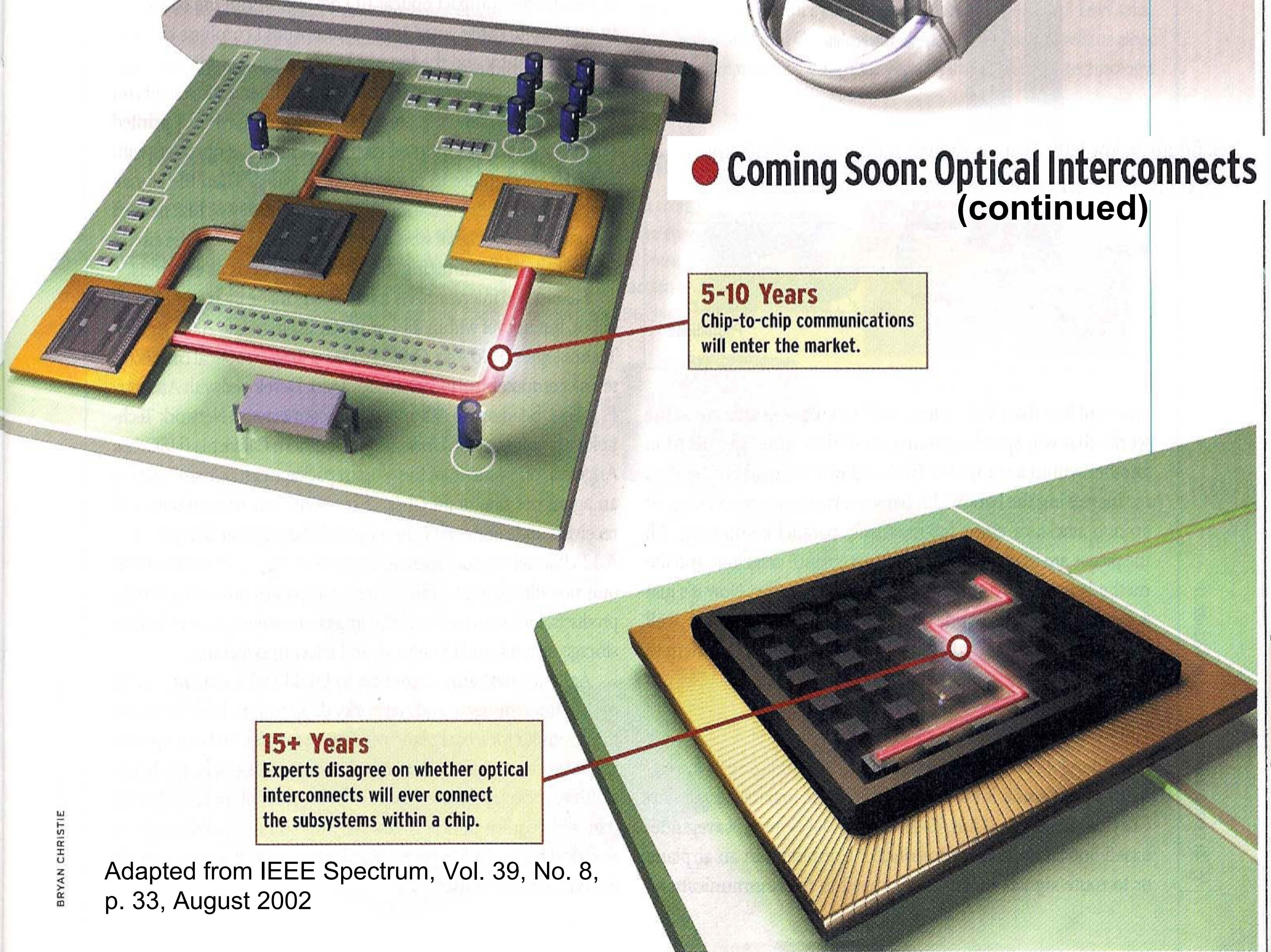
- **Business**
  - Increasing the number of manufacturers that automate processing.
  - Automating alignment processes to reduce costs by deploying standardized carriers and systems.
  - Keeping the optoelectronics packaging industry moving forward as manufacture continue to outsource.
  - Increasing the use of open software to control processing equipment.

# Coming Soon: Optical Interconnects

This approach to signal transfer is moving from longer-distance applications, such as linking separate computers, to joining chips within a computer.


Adapted from IEEE Spectrum, Vol. 39, No. 8, p. 33, August 2002

# Coming Soon: Optical Interconnects (continued)




Adapted from IEEE Spectrum, Vol. 39, No. 8, p. 33, August 2002

# CHALLENGES FOR OPTICAL INTERCONNECTS

- **Viable low-cost manufacturing of**
- **Chip-compatible, high-precision 3D micro-optical pathways that**
- **Integrate all microelectronics and optoelectronics components to**
- **Interface/interconnect these optoelectronic/microelectronic transceivers**
- **Make optoelectronics mainstream for such high volume applications as backplanes in PCs (short term), chip-to-chip (mid term), and perhaps, intra-chip within 15+ years.**
- **CD or DVD transceivers cost about $1.00 but telecom transceivers cost more than $2000.**

# IPC – Issues/Challenges in Optoelectronics Packaging

- Few broadly accepted standards – Main players could improve cooperation to make proprietary data open to the industry and encourage competition and lower prices (analogous to the early days of surface mount technology).

- OE costs orders of magnitude more when compared to microelectronics on a “connected device” basis.

- High cost of most photonic devices accepted by a “seller’s market” attitude and by past focus on quick output, high performance, but not cost redution.

- Innovation needed to reduce component costs and to increase component robustness/reliability.

# Next Steps

## Economic Assessments:

1. Develop convincing arguments that the benefits of consensus-based planning outweighs the costs associated with such planning.

2. Determine economic advantages and disadvantages of future scenarios.

## Next Steps (continued)

**Workshops:**

3. **Identify key subsystems and technology performance gaps between what is available today and what will be needed; e.g., to make optoelectronics packaging mainstream and thereby low cost.**

# Conclusions

**Consensus-based planning offers a way to determine priorities in investing funds to support additional R & D to remove technology gaps between what is available and what the markets require.**

**In order to deliver its full potential, the optoelectronics packaging industry needs improved industry, university, and government collaborations.**

**http://www.eeel.nist.gov/812/itrcs.html**
**http://www.eeel.nist.gov/812/files/slides2.pdf**

# Technology Roadmaps

**“No one is big enough to drive the totality of the infrastructure and pre-competitive investments on their own.”**

----- Avtar Oberai, formerly from IBM and a founding director of SEMATECH, in *Compound Semiconductor* **5**, 44 (April 1999).